The Ecological Cycling of Colored Dissolved Organic Matter

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LONG-TERM GOALS

The prediction of water-leaving radiance in coastal waters is strongly dependent on a quantitative prediction of the depth-dependent distribution of Colored Dissolved Organic Matter [CDOM] in the water column. The goal of this project is to support and synthesize laboratory and field experiments conducted by the ONR Environmental Optics Program. Our part of this larger project is to develop a quantitative understanding of the physical, chemical, optical, and biological interactions impacting CDOM cycling, and to codify this understanding into a numerical simulation, EcoSim 2.0.

OBJECTIVES

1)   Provide satellite image analysis and meteorological support for ONR CDOM cruises.

2)   Provide quantitative data synthesis support for chemical, biological, and physical interactions of CDOM data.

3)   Develop ecological equations for CDOM cycling in the coastal marine environment.

APPROACH

We hypothesize that CDOM cycling is a deterministic process, one that can be explained by physical, chemical, and biological interactions. Furthermore, coupling experimental data with environmental modeling will lead to the development of a set of ecological equations that will resolve the sources and sinks of CDOM, and the impacts on water column IOPs and AOPs. A previous one-dimensional numerical simulation of the bio-optical properties of the Sargasso Sea (Ecological Simulation 1.0 (EcoSim 1.0) Bissett et al., 1999a; Bissett et al., 1999b) suggested that the cycling of CDOM could be mathematically described and validated. In this case, the EcoSim 1.0 results were validated against the multi-year bio-optical time series program operating at the Bermuda Atlantic Time-series Station (BATS) (Siegel et al., 1996; Siegel et al., 1995). In particular, simulated CDOM did not co-vary with the particulate organic absorption or the chlorophyll a concentration, as was previously assumed in these oligotrophic environments (Gordon et al., 1983; Smith et al., 1981).

Separation of the CDOM signal from the particulate signal in oligotrophic regions is important for understanding the propagation of light to depth, and its impact on water-leaving radiance signals used

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14. ABSTRACT

The prediction of water-leaving radiance in coastal waters is strongly dependent on a quantitative prediction of the depth-dependent distribution of Colored Dissolved Organic Matter [CDOM] in the water column. The goal of this project is to support and synthesize laboratory and field experiments conducted by the ONR Environmental Optics Program. Our part of this larger project is to develop a quantitative understanding of the physical, chemical, optical, and biological interactions impacting CDOM cycling, and to codify this understanding into a numerical simulation, EcoSim 2.0.

15. SUBJECT TERMS					
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in satellite oceanography. These regions cover approximately 80% of the world's oceans. However, the CDOM signal can be 1-3 orders of magnitude higher on coastal shelves and near-shore regions. These higher signals result in part from the higher primary productivity found in coastal regions, but also result from the loading of CDOM from the outflows of rivers and estuaries. Prediction of in-water Inherent Optical Properties [IOPs] and the resultant water-leaving radiance [L_w] would require that we accurately address the ecological cycling of CDOM, i.e. the chemical, photochemical, biological, and physical sources and sinks of CDOM in the near-shore region.

WORK COMPLETED

The work of FY2001 demonstrated the relative importance of the shoreward boundary conditions to simulating the nearshore IOPs on the WFS. This boundary condition is extremely variable in time (Figure 1 and 2). An adequate forecast of the CDOM dynamics in the nearshore environment will require accurate boundary conditions within a high-resolution three-dimensional circulation model. The work in FY2002 was split into trying to relate freshwater fluxes on the WFS to the high color signals for the entirety of 1998, as well as incorporating the EcoSim 2.0 CDOM dynamics into a high-resolution, data assimilative, physical circulation model of the New Jersey Bight.

RESULTS

West Florida Shelf

Figure 1 and 2 shows before and after Tropical Storm Mitch images of the Charlotte Harbor region of the WFS. These increase in the SeaWiFS estimated adg(412) may be directly related to the outflows of the Peace and Caloosahatchee Rivers (Figure 3). These outflows contain very high concentrations of DOC (>1000 µmol C l-1) and DON (>60 µmol N l-1). The direct relationship between color and DOC/DON can be difficult to establish, but these waters have a linear relationship between absorption and fluorescence and salinity (P. Coble, USF, per. comm.), and it is clear from these images that color appears to be correlated with low salinity events in this region. The importance of these events may be seen in Figures 1 and 2 in that there is a >6X increase in dissolved absorption at 412nm from offshore to onshore on this oligotrophic shelf. Such an extreme change in dissolved optical properties is not seen from in situ processes driven by autocthonous processes. Thus, any prediction of the nearshore IOPs in regions of the world similar to this oligotrophic shelf will require a reasonable prediction of the fresh water/estuarine fluxes prior to estimating the attenuation of blue light.

New Jersey Bight

This work is coupled to the HyCODE initiative to predict the time varying, 3 dimensional, depth-dependent distributions of the IOPs, and the commensurate water-leaving radiance. This simulation is part of the transition package of EcoSim 2.0 (ES2) and required the recoding of WFS ES2 CDOM code into a version coupled with the Region Ocean Modeling System (ROMS, Song et al., 1994). The ES2 was integrated into the ROMS code during FY2002 and the validation phase of this integration is on going. During this validation phase, it became apparent that there were some inherent errors in the physical solution that were causing some downstream difficulties for the ecological equations.
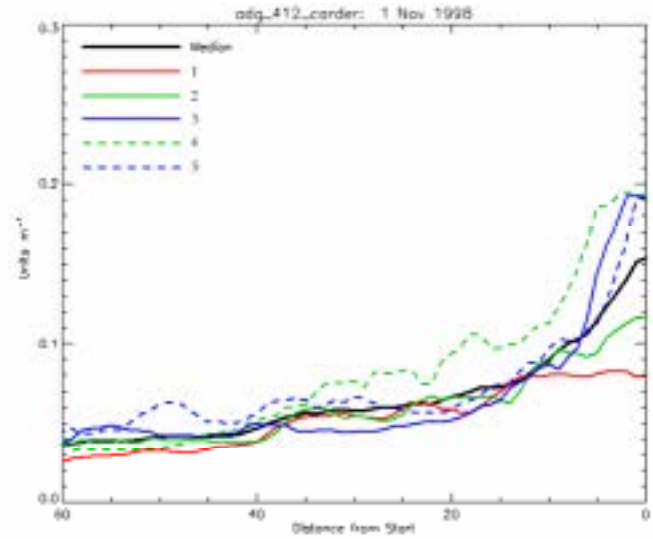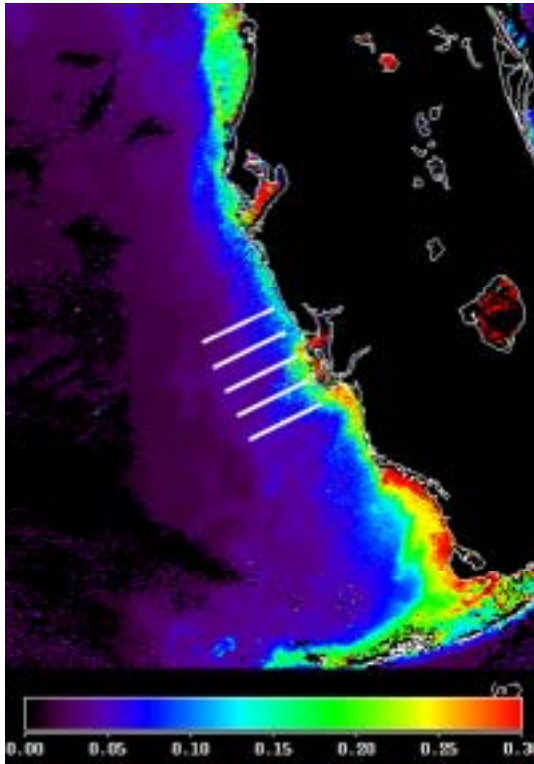
Figure 1. SeaWiFS estimated $a_{dg}(412)$ before TS Mitch (a) over the WFS display minimal DOM absorption in the region of the barrier islands surrounding Charlotte Harbor (~ 0.175m^{-1}). The WFS has been divided into 5 parallel transects for analysis; (b) Transects are interpreted from the start of the transect lines (nearshore) to a distance of 60 km from the start of the transect line (offshore). The median transect displays absorption readings between (0.153-0.04 m^{-1}) transect 1 (0.08-0.025 m^{-1}), transect 2 (0.15-0.04 m^{-1}), transect 3 (0.19-0.04 m^{-1}), transect 4 (0.19-0.04 m^{-1}), and transect 5 (0.19-0.04 m^{-1}).
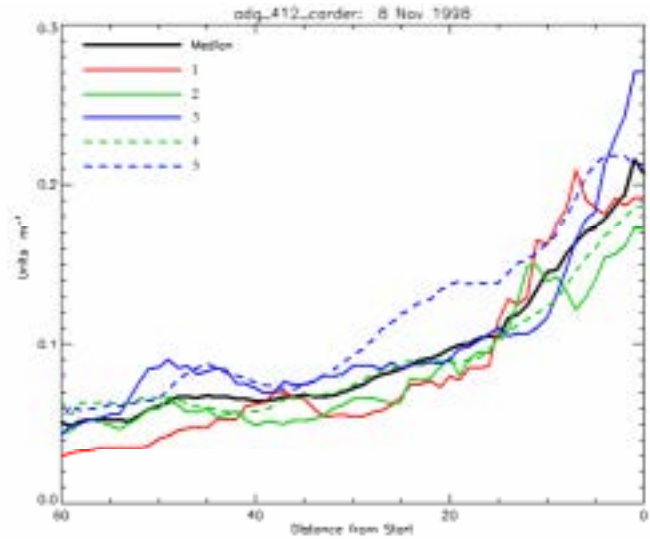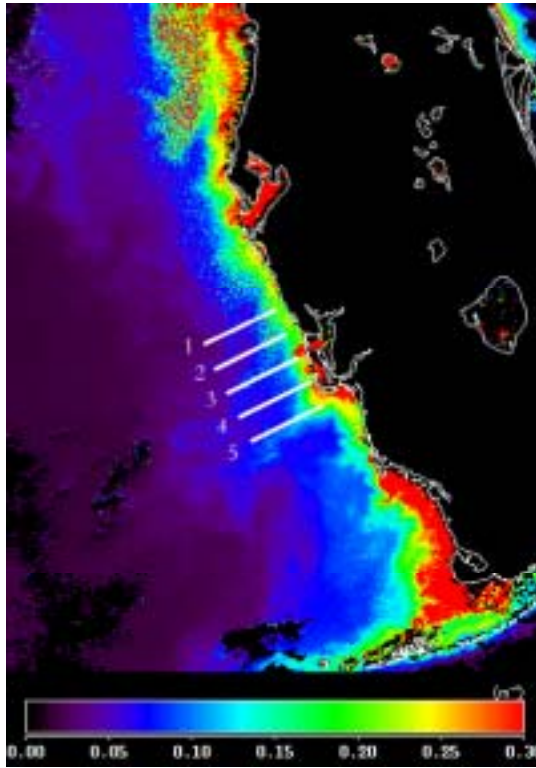
Figure 2. SeaWiFS estimated $a_{dg}(412)$ after TS Mitch (a) over the WFS display increased DOM absorption in the region of the barrier islands surrounding Charlotte Harbor (~ 0.3 m^{-1}) . The WFS has been divided into 5 parallel transects for analysis; (b) Transects are interpreted from the start of the transect lines (nearshore) to a distance of 60 km from the start of the transect line (offshore). The median transect displays absorption readings between (0.21-0.05 m^{-1}) transect 1 (0.19-0.03 m^{-1}), transect 2 (0.172-0.042 m^{-1}), transect 3 (0.27-0.042 m^{-1}), transect 4 (0.198-0.06 m^{-1}), and transect 5 (0.21-0.06 m^{-1}).
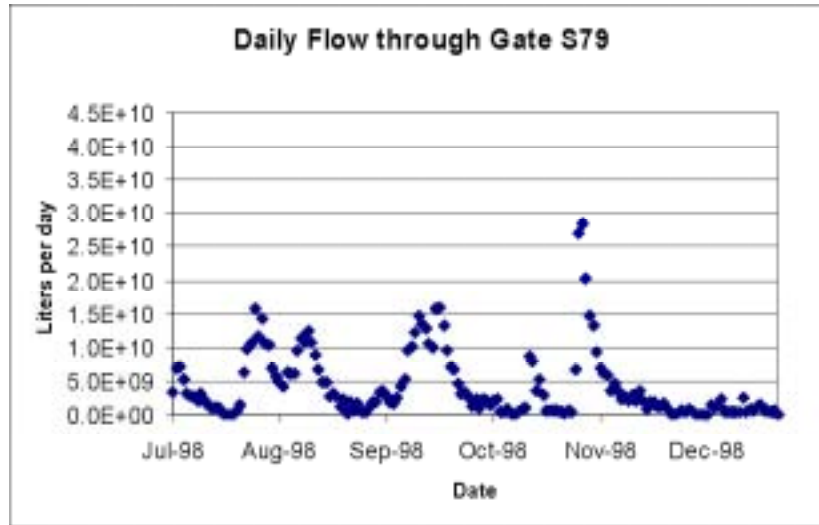
Figure 3. Fresh water flows through the head of the Caloosatchee Estuary (lower Charlotte Harbor). Peak on November 6, 1998 of 2.84E+10Ld^{-1} results from TS Mitch and is mirrored by flows from the Peace River in the upper Charlotte Harbor.

These difficulties began with spatial discrepancies, particularly around the LEO sites that are related to the history of the water masses. Figure 4 shows the SST from a morning pass of AVHRR and the simulated temperature field on July 15th. There are two simulated "hot" water features that are not evident in the AVHRR fields. These features are advected towards the shore by the 21st. While discrepancies of the simulated temperatures are reduced as time progresses, the simulated history of the water mass "remembers" the higher temperatures, as the growth and grazing processes are significantly different for the warmer waters. In this case, there is approximately 50% increase in the growth and loss processes in the "hot" water, than would have been estimated from the actual data. The advection of these water mass onto the shore alters the expected IOPs (not shown) as these are a function of the biomass growth, loss, and accumulation processes.

The hot water features appear to be artifacts of the data assimilation scheme used for temperature and salinity (Arango per. comm.). The assimilation scheme uses and interpolates field data into a three dimensional grid, and then extrapolates the data across the domain of the model. In this case, it appears that the extrapolation of interpolated field data created water mass properties, outside of the collection domain, that were unrealistic. While these values were not evident in the LEO domain during the course of the COMOP experiment, there inclusion into the larger domain impacted the ecological and optical history of the water masses that were advected into the LEO domain.

In addition to these initialization and assimilation issues, the physical simulation also appeared to be mixing the non-labile fraction of the CDOM pool far too rapidly. Figure 5 shows the distribution of non-labile CDOM at the start and end of the HyCODE simulation. This relict CDOM pool had its photolytic loss processes turned off for the testing phase, and it can be seen that there was a 30% loss of CDOM from the simulated physical processes. It was found that there was a logic bug in both the KPP and Mellor/Yamada mixing schemes that resulted in a very large di-pycnal mixing term. These physical problems are being corrected and we expect new ecological runs in the next few weeks.
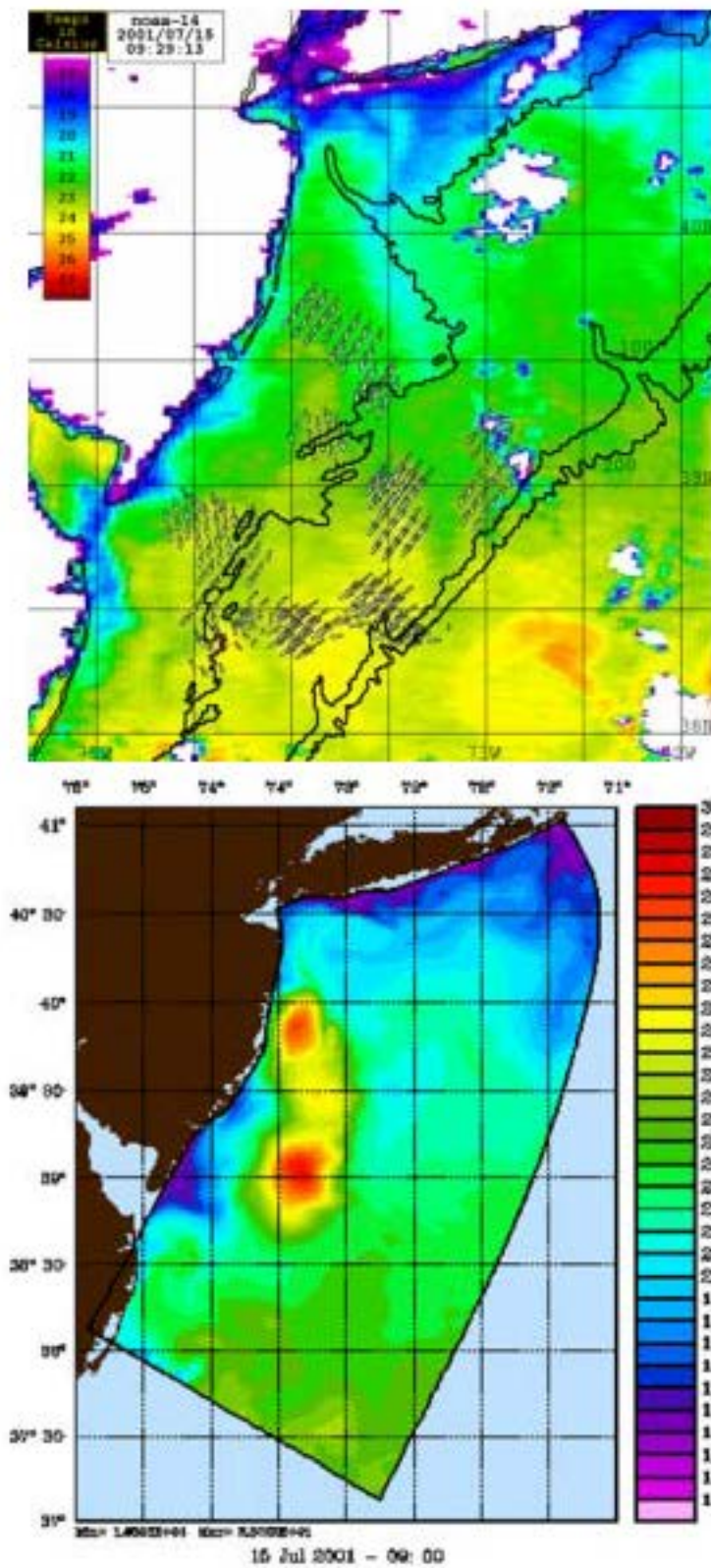
Figure 4. AVHRR SST (top) and simulated SST (bottom) on July 15, 2001 of the New Jersey Bight. Hot spots (approximately 28°C) along the coast not observed in the AVHRR SST are the results of inaccurate data assimilation techniques.
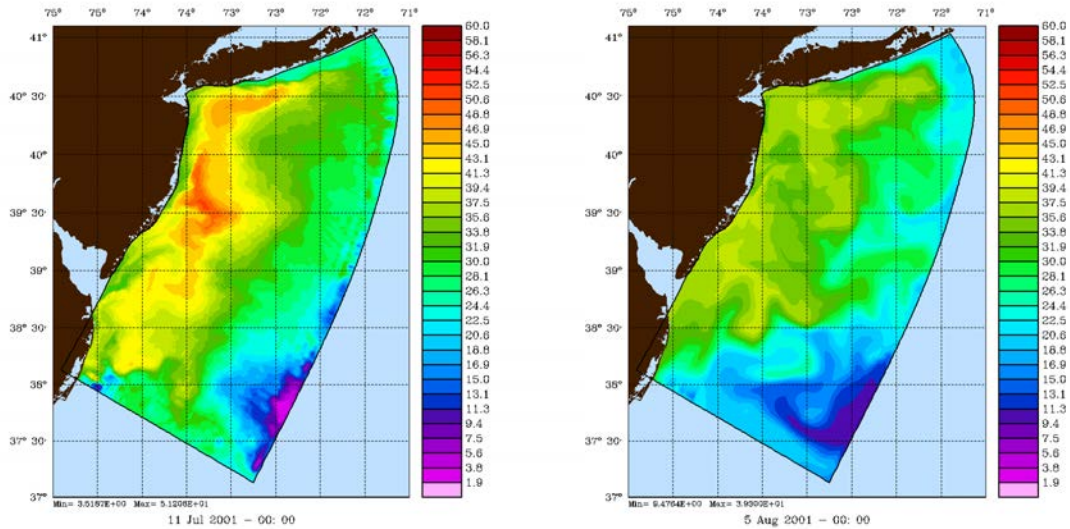
Figure 5. Simulated non-labile CDOM from 3-D New Jersey Bight EcoSim 2.0 simulation during Summer 2001. The photolytic loss processes have been shut off and there is still a loss of 30% resulting from mixing of low concentration bottom waters with high concentration surface waters.

IMPACT/APPLICATIONS

To forecast the clarity of the water column over both short- and long-term time horizons requires an accurate quantification of the ecological cycling of CDOM. Incorporation of a validated set of CDOM equations into a larger three-dimensional ecological simulation will increase the veracity of the predictions of Inherent and Apparent Optical Properties [IOPs and AOPs], and help achieve the goal of forecasting optical properties as a function of the biological, chemical, and physical forcing.

TRANSITIONS

The ES2 code has been open-sourced and is part of the distributed ROMS code (http://marine.rutgers.edu/po/models/roms/index.php). The development of this physical model and its transition to the Terrain-following Ocean Modeling System (TOMS) is also being supported by ONR.

RELATED PROJECTS

1) Robert Chen (UMB) was chief scientist on the ONR-funded CDOM cruise, and collects the spatial distribution of CDOM, as well as a suite of other environmental variables with the ECOShuttle.

2) Mary Ann Moran (U of Georgia) and Richard Zepp (EPA) are conducting laboratory and field measurements on the photolysis of CDOM, as well as the bacterial utilization of in situ and photodegraded CDOM.

3) William Miller (Dalhousie, CA) is conducting experiments on the photolysis of CDOM as a function of the spectral distribution of irradiance.

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